LEGIBILITY NOTICE

1

LA-UR -89-2971

CONF-900122--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

LA-UR--89-2971

DE89 016780

TITLE: A Low Threshold EAS Array for Gamma-Ray Astronomy at Los Alamos

AUTHOR(S): P. L. Burman, C. M. Hoffman, D. E. Nagle, M. E. Potter, V. Sandberg, D. Berley, C. Y. Chang, B. L. Dingus, J. A. Goodman, T. J. Haines, M. Stark, D. E. Alexandreas, S. Biller, G. Dion, X-Q. Lu, P. R. Vishwanath, G. B. Yodh, T. Turner, S. White, A. Zych, S. Freedman, D. Krakauer, and R. Lamb

SUBMITTED TO: The Proceedings of the XXI International Cosmic Ray Conference, Adelaide, Australia, January 6-19, 1990 by University of California, Irvine (August 3, 1989)

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DISCLAIMER

Category HE 7.3-11

A LOW THRESHOLD EAS ARRAY FOR GAMMA-RAY ASTRONOMY AT LOS ALAMOS

R.L. Burman, C.M. Hoffman, D.E. Nagle, M. E. Potter, V. Sandberg
Los Alamos National Laboratory, Los Alamos, NM.
D. Berley, B.L. Dingus, J.A. Goodman, T. J. Haines, M. Stark
University of Maryland, College Park, MD.
R.W. Ellsworth
George Mason University, Fairfax, VA.
D.E. Alexandreas, S. Biller, G. Dion, X-Q Lu, P.R. Vishwanath, G.B. Yodh
University of California, Irvine, CA.
T. Tumer, S. White, A. Zych
University of California, Riverside, CA.
S. Freedman, D. Krakauer
Argonne National Laboratory, Argonne, IL.
R. Lamb
Iowa State University, Ames, IA.

presented by Michael Potter

Abstract

A new type of extensive-air-shower (EAS) array is described that achieves a low energy threshold, large area, high duty factor and large muon coverage. By placing a regularly-spaced grid of phototubes just below the surface of a shallow pond, the Cherenkov light of particles in an air shower striking the water can be detected, resulting in a primary energy threshold of less than 1 TeV. This highly sensitive array can thus be used to span the gap of information between the existing air Cherenkov techniques at 1 TeV and the existing EAS arrays at 100 TeV.

<u>Introduction</u> Within the last 5 years, the new fields of very-high energy (VHE, 100 GeV–100 TeV) and ultra-high energy (UHE, > 100 TeV) gamma-ray astronomy have produced some remarkable and exciting results. Signals have been observed from compact astrophysical objects giving rise to the possibility of studying the interactions of tagged neutral particle beams (presumably gamma rays) at energies well beyond those accessible at any terrestrial accelerator.

Of special note are detections, by the Cygnus collaboration at Los Alamos (B. Dingus *et. al*, 1988) and by the Kiel group (M. Samorski and W. Stamm, 1983), of UHE extensive air showers from Hercules X-1 and Cygnus X-3 that contain anomalously large numbers of muons, not expected on the basis of conventional theories of gamma-ray interactions. The excess muons suggest that the cosmic gamma rays interact as if they were strongly-interacting particles. Either the nature of photon interactions changes at these extremely high energies, or the primary particles are not photons but are some hitherto unknown light, neutral particle; either of these possibilities would reflect exciting, new physics.

The studies have been made with atmospheric Cherenkov detectors for gamma rays near 1 TeV and with air shower arrays above 100 TeV. A cosmic ray striking the atmosphere produces a shower of particles. An atmospheric Cherenkov detector observes the radiation emitted when electrons and positrons in the shower travel faster than the speed of light in air. These detectors can operate only on clear, moonless nights, and can observe only one source at a time. An air shower array consists of a number of widely spaced scintillation counters that detect shower particles that survive to ground level; thus a site at high elevation is desirable. Air shower arrays observe the entire sky, 24-hours per day, in any weather, and are therefore better suited for searching for new or sporatic sources.

The Cygnus collaboration is proposing to build and operate a major new broad-band gamma ray observatory to cover the entire energy range from 1 TeV to 10 PeV. The detector would improve the sensitivity of the existing Cygnus array to UHE gamma rays and cover the largely unexplored region from 1 to 100 TeV, allowing a study of the energy dependence of the anomalous gamma-ray interactions and a search for more VHE sources.

The Proposed New Detector Many of the concepts of the proposed detector were first discussed by the GRANDE collaboration (H. Sobel *et. al.*, 1988), who proposed a large water Cherenkov detector for both gamma-ray astrophysics and neutrino astrophysics. The propos d broad-band gamma ray detector at Los Alamos will also consist of a large volume of water in which the Cherenkov light, emitted when the shower particles traverse water, is observed; however, this volume of water will be shallow. The Los Alamos detector differs from the GRANDE air shower array primarily in that, although smaller, the Los Alamos detector operates with a much lower energy threshold (< 1 TeV), and for a significantly lower cost.

The combination of several factors makes this detector design particularly attractive at Los Alamos. First, there is a water pond owned by Los Alamos National Laboratory at an elevation of 2650-m with a plastic liner and cover that would be ideal for the detector. The air shower would be detected by 500 photomultiplier tubes spaced 3 meters apart, located one meter below the surface; 150 tubes near the bottom of the pond and optically isolated from the top layer would measure the muon content of the showers. The pond, which measures 60-m by 80-m at the water surface and is about 8-m deep, is currently used as a reservoir for the hot-dry rock geothermal program at Los Alamos. An artist's conception of the detector is shown in Figure 1. Second, the Burle Corporation, in collaboration with Los Alamos, has developed a 10" photomultiplier tube with excellent timing characteristics that would lead to superior angular resolution and background rejection. Third, it has recently been shown that the Crab nebula is a constant source of 1 TeV photons (T.C. Weekes *et. al.*, 1988); this water Cherenkov detector would be the first air shower array capable of observing this "standard candle" and the only detector that could measure its energy spectrum.

This detector would detect a much larger fraction of the shower particles ($\approx 30\%$) compared with traditional air shower arrays ($\approx 0.5\%$). In addition, the photons from the air shower are also detectable in the water. Both of these factors, in addition to the high altitude of the array, contribute to the low energy threshold of the array. By suplementing the water detector with outlying scintillation counters, the detector will retain the sensitivity of the present Cygnus array to UHE gamma rays, but with improved angular resolution and muon detection. Thus, the water Cherenkov technique appears to be optimum for the large sensitive-area detector that is needed to observe lower energy gamma rays.

In Figure 2, the expected energy spectrum of all detected events is shown; note that there are a large number of events even below 1 TeV. Figure 3 shows the expected angular resolution as a function of the energy of the primary; angular measurements of this precision are unprecedented in this field and imply greatly increased sensitivity. For comparison, the present Cygnus detector has an angular resolution of 0.8° above 100 TeV. Monte Carlo studies show that we will be able to search for anomalous muon content in gamma ray showers down to 5 TeV; this includes an energy region for which the nature of photon interactions will soon be measured in accelerator experiments. Rough estimates indicate that this detector would cost a few million dollars (US) and require about two years to build.

Conclusions The construction of the water Cherenkov air shower detector will provide a unique observatory for VHE and UHE gamma-ray astronomy; no other detector, either existing or proposed, can operate with such high duty factor and low energy threshold for such a low cost. These features, along with the ability to study the muon content of showers, are needed to understand the puzzling observations of VHE and UHE gamma rays from Cygnus X-3 and Hercules X-1 that have recently been made. In addition, the broad energy coverage of this detector allows the unique possibility to measure the energy spectrum of the Crab nebula above 1 TeV.

References

B. Dingus *et. al.*, 1988, Phys. Rev. Lett. **60**, 1785.

B. Dingus *et. al.*, 1988, Phys. Rev. Lett. **61**, 1906.

M. Samorski and W. Stamm, 1983, Astrophys. J. Lett. **268**. L17.

H. Sobel *et. al.*, 1988, GRANDE Proposal, UCI Neutrino No.

T. C. Weekes *et. al.*, 1988, Astrophys. J., submitted.

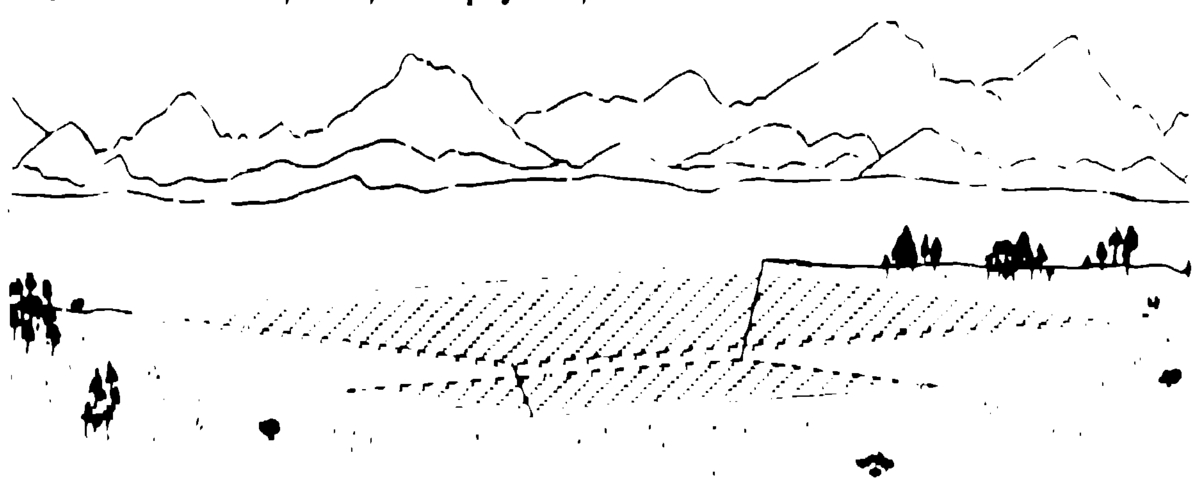

Figure 1 An artist's conception of the proposed water Cherenkov detector.

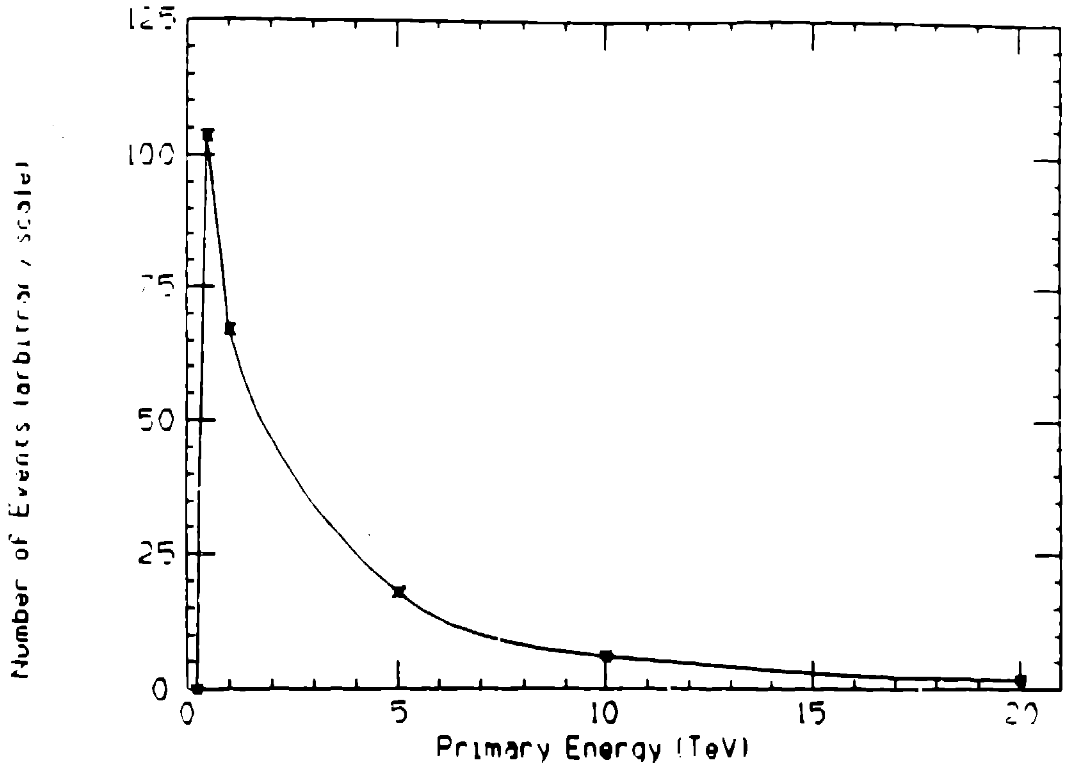

Figure 2 The expected energy spectrum of events triggering the detector. Note that many events are below 1 TeV.

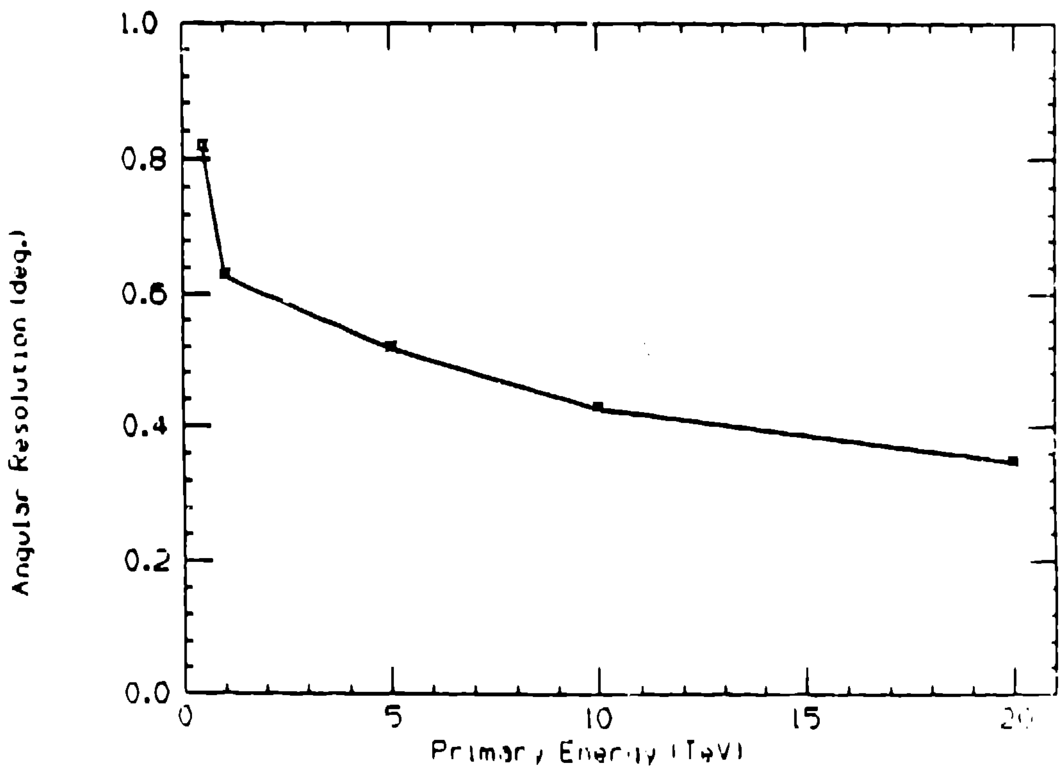

Figure 3 The expected angular resolution of the detector as a function of primary photon energy.